



Evaluation of Vertical Fed-Biomass Cookstove in Reducing Air Indoor Pollution: The Sunken Pot Design

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Abstract

Responsive to contribute in reducing the ill effect of indoor air pollution that claims millions of lives of women and children in biomass dependent households from developing countries including Philippines. The vertical fed biomass cookstove that BPSU developed was further tested using different pot set ups; the sunken pot, top fitted and open-fired. Following standard test like water boiling test (WBT), controlled cooking Test (CCT), CO, CO₂, Particulate Matter 10 and 2.5 and fuel consumption rate (FCR) was carried out. Better Heat utilization efficiency was recorded for the two stoves under sunken and top fitted set up compared to open fired set up. No significant differences were noted between the three (3) set ups for the two stove in terms of WBT, CCT, CO₂ and CO emission. However, FCR for of the stoves for the pot set ups are significant making the sunken and top fitted a better way to position the pot during cooking. Evidence showed that pot under open fired set up emission was way beyond the US EPA threshold for good Indoor Air Quality (IAQ) making more hazardous compared to the sunken pot and top fitted set up with emissions lower the threshold for good Indoor Air Quality.

Prioritizing good health in the household, the developed cookstove by BPSU will ensure to produce less emission that can affect the well – being of the user. This will lead as well in getting an affordable product due to less cost of production, while producing a cleaner energy from it, compare to the traditional biomass cookstove.

According to World Health Organization (WHO) report in 2016, Philippines has earned the distinction of having the region's second biggest number of deaths due to indoor air pollution, data gathered by the world health agency showed that close to 84 deaths per 100,000 Filipino population were recorded. <https://newsinfo.inquirer.net/987262/ph-ranks-2nd-in-asia-pacific-in-deaths-due-to-household-pollution>

Keywords: biomass, vertical-fed, indoor air pollution, sunken pot

Introduction

The global and local issues concerning environment, energy and health should be addressed by all means and at all levels of our society considering our country is still with the developing status if we wanted not to be adversely affected by its impact in the foreseeable future. (Lacayanga, 2016).

Our household is 86% dependent on biomass as fuel for cooking and other similar activities which according to reports inefficient cook stoves caused increase in greenhouse gas emission (GHG) and health problem particularly respiratory related ailments. In addition to that, expensive and declining supply of fossil fuels pressing household to shift to biomass energy fuel sources.

On the latest findings of the Global Burden of Disease study in 2010 shockingly revealed that Indoor Air Pollution (AIP) created by inefficient biomass cook stoves was found to be the 4th cause of premature death worldwide. This situation continues to occur up to the present due to issues on energy cost at inefficient stove design particularly the biomass stoves. With no exception, Philippines is a contributor the accumulation of GHG and short-live black carbon pollutant (SLCP) being pre-dominantly biomass dependent.

In response to this concern BPSU developed the Vertical-Fed Biomass cook stove duly recognized by the Clean Cooking Alliance of the United Nations Foundation and registered with the Intellectual Property Office (IPO). This stove significantly reduced Indoor Air Pollution (IAP) and the SLCP. However, current performance suggests in terms of heat utilization efficiency (HUE) need to be increased which will contribute further to the reduction of indoor pollution, fuel heat utilization efficiency of the stove and reduce energy cost and consumption of the biomass using households.

According to Chowdhury, S. et al. 2023, an estimated 2.3 (1.6–3.1) million premature deaths occur each year worldwide as a result of direct exposure to household fine particle air pollution (HAP) linked to inefficient burning of fuels (wood, charcoal, coal, agricultural wastes, kerosene, etc.) for cooking, space heating, and lighting. When it comes to outdoor ambient fine particulate air pollution (AAP), house-borne particulate pollution (HAP) from indoor sources is a major contributor in low- and middle-income countries. It frequently contributes more than well-known sources such as industry, road transportation, coal-fired power plants, brick kilns, and construction dust. We examine scholarly works that have been published and model the worldwide and significant sub-regional contributions of HAP to AAP. We outline the advantages and disadvantages of the present understanding of HAP's role in AAP and the associated effects on public health and provide recommendations to improve these estimates. We find that HAP is a dominant source of ambient fine particulate matter (PM_{2.5}) globally — regardless of variations in model types, configurations, and emission inventories used — that contributes approximately 20 % of total global PM_{2.5} exposures. There are large regional variations: in South Asia, HAP contributes ~ 30 % of ambient PM_{2.5}, while in high-income North America the fraction is ~ 7 %. The median estimate indicates that the household contribution to ambient air pollution results in a substantial premature mortality burden globally of about 0.77(0.54–1) million excess deaths, in addition to the 2.3 (1.6–3.1) million deaths from direct HAP exposure. Coordinated global action is required to avert this burden.

According to estimates, 97% of South Asians reside in regions where the previous World Health Organization (WHO) Air Quality Guideline of 10 $\mu\text{g}/\text{m}^3$ is exceeded. South Asian countries have some of the highest ambient PM_{2.5} exposure levels in the world (Chowdhury and Dey, 2016; David et al., 2019; Ravishankara et al., 2020). According to the MAPS Working Group (2018), sources connected to the burning of coal and biomass as well as other dust-producing human activities are the main causes of ambient PM_{2.5} exposures in South Asia.

Furthermore, natural and aeolian dust may be responsible for a significant portion of ambient PM_{2.5} in South Asia (Chowdhury et al., 2022; MAPS Working Group, 2018). It should be mentioned that, similar to East Asia, there are significant regional variations in the sources of PM_{2.5} in South Asia. Nevertheless, in the most populated areas of the region, domestic solid fuel usage has been found to be the main contributor (Chowdhury et al., 2019b; Upadhyay et al., 2018). While wood is the most often used solid fuel in South Asia, other fuels such as charcoal, dung cakes, and agricultural wastes are also utilized (Abbas et al., 2020). The regional authorities have started implementing programs to switch families from using solid fuels to cleaner fuels (for example, the Indian government introduced the Pradhan Mantri Ujjwala Yojana (PMUY) to give women in low-income households subsidized LPG connections). Nonetheless, despite extensive efforts to promote cleaner fuels, as of 2019 in the three most populous countries in South Asia—India, Pakistan, and Bangladesh—roughly 61%, 53%, and 76% of the population, respectively, still cook with solid fuels (Jeuland et al., 2015; Kar et al., 2019; Mani et al., 2020; Pillarisetti et al., 2022; Smith, 2018). In South Asia, home use of solid fuels is the main source of ambient PM_{2.5}, according to several studies.

In South Asia, the contribution of HAP to ambient PM_{2.5} exposures was likewise documented by nine of the worldwide bottom-up investigations. Six regional modeling studies for India were also discovered by us (see Table S2 for a thorough review; Chowdhury et al., 2019b; Conibear et al., 2018; Guo et al., 2017; MAPS Working Group, 2018; Sharma et al., 2018; Upadhyay et al., 2018). According to international research, HAP contributes to ambient PM_{2.5} in South Asia by at least 18% and maybe up to 50%. 29.5% is the median amount that HAP emissions contribute to AAP. Our results are in agreement with seven global and regional modeling studies assessed in a prior research (Chowdhury et al., 2019a).

We find that HAP contributes approximately 60% more to ambient PM_{2.5} exposures in South Asia than emissions from transportation, at least four times more than open burning, and higher than emissions from industries and coal-fed power plants. According to 46 top-down studies conducted in South Asian nations, burning biomass (including domestic and agricultural) contributes 15% on average to ambient PM_{2.5} (Hopke et al., 2020).

The main source of PM_{2.5} exposures in East Asia and China is the combustion of fossil fuels in industries and power generation (Pui et al., 2014; Zhang et al., 2019; Zheng et al., 2021). Since 2014, China has implemented a number of successful air pollution mitigation initiatives (Lu et al., 2020; Silver et al., 2018; Zhang et al., 2019). However, until recently, mediating household emissions was not a priority (Lu et al., 2020; Meng et al., 2019).

Many Chinese households have moved away from using coal for cooking over the past five years in favor of greener fuels, such as electricity, natural gas, liquified petroleum gas, and biogas. Solid fuels continue to be the most common energy source for heating, particularly in Northern China, despite a recent study showing that the consumption of wood and crop residues in rural China fell by 63% and 51%, respectively, between 1992 and 2012. (Tao et al., 2018)

Nine bottom-up global modeling studies that report the contribution of HAP to ambient PM_{2.5} over China have been identified. These include Aunan et al. (2018), the GBD MAPS working group (2016), Liu et al. (2016), Reddington et al. (2019), Shen et al. (2019), Timmermans et al. (2017), Yun et al. (2020), and Zhao et al. (2018).

The majority of regional studies on the remaining parts of East Asia—such as Japan, South Korea, and Taiwan—are sparse. It is difficult to distinguish signals from transboundary pollution originating in China from those released locally inside these countries because of the substantial amount of pollutants carried from the Chinese mainland to these countries. Global modeling studies (e.g., Chowdhury2022) reveal that in South Korea and Japan, power generation and industrial emissions account for almost half of the total PM_{2.5}, with HAP contributing less than 10%.

While home emissions in China and South Korea fell after 2014 and climbed between 2005 and 2010, residential emissions in Japan have been declining since the early 2000s (Li et al., 2017). Out of the eight regional investigations, three research (Aunan et al., 2018; Yun et al., 2020; Zhao et al., 2018) used the integrated population weighted exposure (IPWE) to PM_{2.5} formulations to report the contribution of HAP to total PM_{2.5} exposures. The population's overall weighted exposure to PM_{2.5} from both ambient PM_{2.5} and HAP is represented by IPWE, which is the weighted sum of PM_{2.5} concentrations in all microenvironments where individuals spend time, such as the kitchen, living room, bedroom, and outdoor spaces.

Methods

The study will evaluate the performance of the vertical fed biomass cookstove that are made of galvanized iron sheet (GI sheet) and the volcanic sand based concrete materials fabricated at the BPSU Abucay Campus.

Performance Testing

Using the test procedures prescribed by the Clean Cooking Alliance (CCA), the following data will be gathered and analyzed during the stove testing;

- Heat Utilization Efficiency (HUE); %
- Fuel Consumption rate (FCR) kg/hr
- Water boiling Test (WBT) performance
- Controlled cooking test (CCT)
- Particulate Matter Emission (PM 2.5)
- Carbon dioxide (CO₂) emission (ppm)
- Carbon monoxide (CO) emission (ppm)

There were 2 studies under this experiment applying the above stated parameters to be tested, collected and analyzed.

Study 1 was the evaluation of the stove fabricated using the most common metal sheet available in the local market which is the Galvanized Iron (GI) sheet. The GI sheet is 1.2 mm thick and cut into desired sizes of fuel feeding port, the pothole and the exhaust chimney.

Study 2 was the evaluation of the stove fabricated using volcanic sand based concrete with reinforcement with similar size of fuel charging port, pothole and exhaust chimney.

Preparation of materials

Stove for evaluation was fabricated based on the criteria of using the most common materials available in the campus. Primarily galvanized iron sheet (GI and volcanic sand characterized by its high heat resistance gathered from nearby construction stores.

The wood fuel was being collected from the trimmings of the campus forest comprising hardwood (mahogany tree). The wood fuel will be cut to 30 cm length and split into smallest diameter as possible. Sun drying of the wood fuel will be carried for 3 days until the moisture is reduced approximately from 13-15 %.

Pre- testing of the equipment such as the CO/CO₂ meters, weighing scale and timers was carried and at the same time the functionality of the stove prior to final testing.

Final testing procedures

Wood fuel are properly weight for every testing trial using the water boiling test (WBT) and controlled cooking test (CCT) are prescribed by the Clean Cooking Alliance (CCA) of the United Nations Foundation.

The desired pot to be used for both testing will be of the same configuration having a parabolic bottom to keep some portion lower than that of the surface of the cook stove top.

Simultaneous testing was carried out using the fabricated stove having the 3-stone stove as the reference stove. Conducting 3 trials for each of the parameters to be tested and record data like time to boil, time to cook, final weight of the water boiled, final weight of the food cooked, CO/CO₂ emissions, particulate matter (PM 1.0 and 2.5), fuel consumption rate and, heat utilization efficiency (HUE) of the stoves tested.

Proper documentation was carried out in any of the test stages to provide an evidence on the conduct of the experiment.

Results

After the analysis of data generated from testing of two (2) stoves made from GI sheet and the concrete the finding are as follows;

For the Heat Utilization performance, it was found out that both the stove has better performance in utilizing the heat from burnt fuels compared to the open fired pot set up that dissipated more heat to the surroundings instead of utilizing it to cook the material.

For both stoves under different pot set ups, no significant differences on their Carbon dioxide (CO₂) and Carbon monoxide (CO) emission was observed.

The stove fuel consumption rate was significantly different. But comparing the means, sunken pot and top fitted pot methods was found to significant differ from the open fired pot set up.

The Particulate Matter emission of the stoves using the same set ups showed great difference when compared to the United State Environmental Protection Agency (US EPA) threshold for good Indoor Air Quality. The average Particulate Matter 10 and 2.5 emission of the sunken pot and top fitted pot are both below the US EPA threshold while the emission of the open fire pot was way beyond the threshold making it more hazardous to human health.

Discussion

Adopting the vertical fed – biomass cookstove in a household in an affordable cost is one of the primary goals of this developed stove of BPSU, which also produces cleaner emission. The design basically lessens the use of woods as the source of heat for cooking. Less consumption of woods can benefit the end user, as they can save money.

On the other hand, the biomass – dependent households might find it challenging where to place the cookstove specifically if they do not have an open area. However, since the pipe where the produced gas flow connected to the stove can be extended, they can put the end of the pipe external, considering some adjustments and limitations.

To understand further the impact of using the BPSU developed stove, following the standard procedures set to evaluate the stove performance, the succeeding discussion were presented for the stove under study.

Heat Utilization Efficiency (HUE); %

The stove Heat Utilization Efficiency (HUE) is a measure of a biomass cook stove performance converts the heat generated from burning biomass fuel that is absorbed by the material to be cooked. Table 1 presents the calculated Heat Utilization efficiency of two stove under evaluation using the sunken pot method, fitted pot and open fired. The better performance of the concrete made cook stove is attributed to the materials it was made. Since heat is confined under the burning chamber the heat is efficiently absorbed by the cooking pot and the materials being heated, in this case water for the water boiling test (WBT) and rice for the controlled cooking test (CCT). Concrete stove performance is far better than GI made stove under the 3 different cook ware set ups. It can be further explained that stove made of GI sheet has greater heat loss outside of its burning chamber instead of the heat utilized to cook the materials inside the cookware or the pot. In the same manner, under open- fire set up much of the heat is discharge instead of the being absorbed by the material inside the cookware or the pot.

Table 1. Heat Utilization of Efficiency of Concrete and GI sheet Stoves

Cookware (pot) set up	Concrete stove (%)	GI stove (%)
Sunken Pot	31.22	23.67
Fitted Pot	28.45	20.41
Open- fired*	18.74	18.86

(*) stove was skirted and set to an ordinary open burning stove

Galvanized Iron Sheet (GI) Sheet Stove

Study 1. The stove evaluated was made from Galvanized Iron sheet (G.I.) sheet under three pot setting the sunken pot (figure 1a) it is the means of setting the pot 6-7 cm below the surface of the top of the stove exposing more area the bottom of the pot to the fire during operation. The top fitted pot (figure 1b.) is a means of seeing the cookware or pot 2-3 cm below the surface of the cook stove exposing lesser area of the pot bottom to fire during operation.

and the open fired set up as the control condition (figure 1c) where pot is set to a typical traditional cooking provided with metal skirt and expose the bottom as sunken and fitted pot.



a. Sunken pot



b. Top Fitted pot



c. Open fired

Figure 1. Showing the different pot set up for the stove testing

Water boiling Test (WBT) performance

The water boiling performance of the GI sheet made stove were analyzed. The analysis of variance in Table 2 revealed that there was no significant difference between the treatments used to test the stove performance. This means that GI sheet made stove performance was not affected by the different pot set ups during the heating operation of 1.5 liter of water using similar cookware or cooking pot.

Table 2. Analysis of Variance GI stove water boiling test (WBT)

Source	DF	Sum of Square	Mean Square	F Value	Pr (>F)
Treatment	2	0.3357	0.1679	0.05	0.9549
Error	6	21.6443	3.6074		
Total	8	21.9800			

There is no significant difference in WBT as observed in different treatments

CV = 12.82%

Controlled Cooking Test (CCT)

The Controlled cooking (CCT) performance of the GI sheet made stove were analyzed. Table 3 shows that there are no significant differences between treatment under this test method for in cooking 300 grams of rice. This means that cooking time for the GI sheet made stove is similar in the 3 different cookware or pot set ups.

Table 3. Analysis of Variance Table GI stove controlled cooking test (CCT)

Source	DF	Sum of Square	Mean Square	F Value	Pr (>F)
Treatment	2	243.7176	121.858	4.56	0.0625
Error	6	160.3175	26.7196		
Total	8	404.0352			

There is no significant difference in CCT as observed in different treatments

CV = 24.44 %

Carbon Monoxide (CO) Emission

Carbon monoxide (CO) is a gas emitted by biomass cookstoves during cooking. It is colorless, odorless and tasteless but dangerous gas. It is an important gas that are monitored in an indoor situation like household. It is a health hazard at some extent of volume present indoor and exposures of the person inside the building. It can reduce the ability of the blood to carry oxygen to the different part of eh body. To maintain a good Indoor Quality Air (IQA) the United State Environmental Protection Agency (US EPA) has set the maximum threshold for good indoor air quality. For the CO level indoor must not exceed 25 ppm. Beyond this limit proper ventilation must be provided or resident are required to vacate the building.

During testing of the GI sheet made stove recorded the average CO emission under 3 different pot set ups is shown in Table 4. Under different pot set ups using the GI sheet made stove the average CO emission was lower than the US EPA threshold which means the indoor quality related to CO is rated good.

Table 4. Cookstove carbon monoxide emission (ppm)

Pot set up	Average CO emission	US EPA threshold
Sunken Pot	2.33	Less the 25 ppm
Fitted pot	3.33	
Open-fired	1.67	

Carbon Dioxide (CO₂) Emission

Carbon dioxide (CO₂) is an important Greenhouse gas that contributes greatly to the global warming. Evidence showed that household biomass cook stove that are inefficient (3-stone stove) are contributors to the CO₂ in the atmosphere considering that there are more the 1 billion households worldwide are still using inefficient biomass burning stove (WHO, CCA-UN Foundation 2020). The s GI sheet made stove emission was recorded and the average data is presented in Table _____. Test result showed that under 3 different set ups the stove emitted average CO₂ that is lower the tan the US EPA threshold for a good indoor air quality.

Table 5. Cook stove carbon dioxide emission

Pot set up	Average CO ₂ emission	US EPA threshold
Sunken Pot	432.3	Less the 650 ppm
Fitted pot	462	
Open-fired	616	

Fuel Consumption (kg/min)

Fuel consumption rate is the stove performance measured in terms of the amount of fuel utilized during the actual test. Table 5 showed that there was significant difference between treatments. The comparison among treatments in Table 6 further revealed that sunken pot and top fitted varies insignificantly while they are significantly different than the open fired pot.

Table 6. Analysis of Variance for Stove fuel consumption (kg/min)

Source	DF	Sum of Square	Mean Square	F Value	Pr (>F)
Treatment	2	0.0001	0.0001	48.01	0.0002
Error	6	0.0000	0.0000		
Total	8	0.0001			

There is a significant difference in fuel consumption as observed in different treatments

CV = 4.71 %

Table 7. Fuel consumption as affected by different treatments, kg/min

Treatment	Means
Sunken pot	0.0190 ^b
Top fit	0.0210 ^b
Open fired	0.0271 ^a

Means with the same letter are not significantly different at 5% level of significance using Tukey-HSD Test

Particulate Matter (PM)10 Emission

Particulate matter 10 is a dust like materials emitted by burning biomass fuel in the households. It usually smaller than Pm 2.5 but also potential cause of respiratory related ailments once inhaled and get into the human body by breathing. The GI sheet made stove performance is shown in the Table 8. Sunken pot and fitted pot has average emission lower than the US EPA threshold for good Indoor Air Quality. This simply means that The first two set ups limit the release of the particulate matter through the stove chimney instead of releasing it outside of the stove inside the kitchen.

Table 8. Cookstove particulate matter emission 10 (microgram/ cu m of air)

Pot set up	Particulate Matter 10 emission	US EPA threshold
Sunken Pot	24.33	Less than 54 microgram/cu m of air
Fitted pot	32.66	
Open-fired	529.67	

Particulate Matter (PM) 2.5 Emission

Particulate matter 2.5 (PM 2.5) according the World Health Organization is the main cause of more than 4 million deaths of women and children globally particularly from developing countries still using open-fire and inefficient cookstoves. In the same manner the Global Burden of Disease Survey mentioned that PM 2.5 are released by cook stove are important concern that needs to addressed globally through innovations and dissemination of improved and efficient stove. For this study sunken pot and fitted pot set up during the operation releases particulate matter lower than the US EPA threshold which means that the cookstove can significantly maintain a good level of indoor air quality. On the other open fire set up releases more than the standard threshold which may cause serious effect on the health of persons exposed it.

Table 9. Cookstove particulate matter emission 2.5 (microgram/ cu m.)

Pot set up	Particulate Matter 2.5 emission	US EPA threshold
Sunken Pot	21.33	Less than 12 microgram/cu m
Fitted pot	25.33	
Open-fired	452	

Concrete Cookstove

Study 2. The stove evaluated was made from volcanic sand based reinforced concrete under three pot setting the sunken pot (figure 1a) and top fitted pot (figure 1b.) and the open fired set up as the control condition (figure 1c).

Water Boiling Test (WBT)

The concrete stove performance evaluated using the Water boiling test (WBT). Table 10 showed that there was no significant difference between the treatment to test the stove performance using the 3 pot set ups namely sunken pot, top fitted pot and the open-fired. This means that regardless of the stove make the pot set up do not differ from each other.

Table 10. Analysis of Variance for the water boiling test (WBT)

Source	DF	Sum of Mean Square	F Value	Pr (>F)
Treatment	2	0.3847	0.1923	0.9545
Error	6	24.5916	4.0986	
Total	8	24.9763		

There is no significant difference in WBT as observed in different treatments

CV = 13.69 %

Controlled Cooking Test

Controlled cooking test (CCT) is a measure of the stove performance under 3 different pot set ups, sunken pot, top fitted pot and open fired. A uniform 300 grams of rice was used to test how will it take for the stove to cook the material having all input like fuel are set almost the same. The analysis of variance in Table 11 shows that there is a significant difference observed from the 3 different treatments referring to the time the stove cooked the rice. In comparing the treatment means, Table 12 shows that sunken pot method and top fitted pot method are not significant different but they are significantly different to the open fired set up. I further explain that open fired pot received much less heat compared to the other set up as reflected in their heat utilization efficiency ((HUE).

Table 11. Analysis of Variance of the stove controlled cooking test (CCT)

Source	DF	Sum of Mean Square	F Value	Pr (>F)
Treatment	2	16.4744	8.2372	0.0309
Error	6	7.5282	1.2547	
Total	8	24.0026		

There is a significant difference in CCT as observed in different treatments

CV = 6.08%

Table 12. Controlled Cooking Test as affected by different treatments, min

Treatment	Means
Sunken pot	17.45 ^b
Top fit	17.47 ^b
Open fired	20.33 ^a

Means with the same letter are not significantly different at 5% level of significance using Tukey-HSD Test

Carbon Monoxide Emission (ppm)

During testing of the concrete made stove recorded the average CO emission under 3 different pot set ups is shown in Table 13. Under different pot set ups using the GI sheet made stove the average CO emission was lower than the US EPA threshold which means the indoor quality related to CO is rated good.

Table 13. Cookstove carbon monoxide emission (ppm)

Pot set up	Average CO emission	US EPA threshold
Sunken Pot	2	Less the 25 ppm
Fitted pot	4	
Open-fired	1.67	

Carbon Dioxide (CO₂) Emission

Carbon dioxide (CO₂) is an important Greenhouse gas that contributes greatly to the global warming. Evidence showed that household biomass cookstove that are inefficient (3-stone stove) are contributors to the CO₂ in the atmosphere considering that there are more the 1 billion households worldwide are still using inefficient biomass burning stove (WHO, CCA-UN Foundation 2020). The s GI sheet made stove emission was recorded and the average data is presented in Table 14. Test result showed that under the sunken pot and top fitted pot set ups different set up average CO₂ emission is lower the tan the US EPA threshold for a good indoor air quality. On the other hand, open fired set up exceeds the US EPA threshold.

Table 14. Cookstove carbon dioxide (CO₂) emission

Pot set up	Average CO ₂ emission	US EPA threshold
Sunken Pot	437.33	Less the 650 ppm
Fitted pot	461.33	
Open-fired	685.67	

Fuel Consumption Rate (kg/min)

Fuel consumption rate is the concrete stove performance measured in terms of the amount of fuel utilized during the actual test. The analysis of variance in Table 16 showed that there was significant difference between treatments. The comparison among treatments in Table 17 further revealed that sunken pot and top fitted varies insignificantly while they are significantly different than the open fired pot.

Table 16. Analysis of Variance of the stove Fuel consumption (kg/min)

Source	DF	Sum of Square	Mean Square	F Value	Pr (>F)
Treatment	2	0.0006	0.0003	25.00	0.0012
Error	6	0.0001	0.0000		
Total	8	0.0006			

There is a significant difference in fuel consumption as observed in different treatments

CV = 7.32 %

Table 17. Fuel consumption as affected by different treatments, min

Treatment	Means
Sunken pot	0.0400 ^b
Top fit	0.0400 ^b
Open fired	0.0567 ^a

Means with the same letter are not significantly different at 5% level of significance using Tukey-HSD Test

Particulate Matter (PM) 10 (microg/cum)

The concrete made stove performance is shown in the Table 18. Sunken pot and fitted pot have average emission lower than the US EPA threshold for good Indoor Air Quality. This simply means that the first two set ups limit the release of the particulate matter through the stove chimney instead of releasing it outside of the stove inside the kitchen. Meanwhile open fired pot emission was enormously higher than the US EPA threshold which means that using this method of setting the pot during operation is a health hazard as what the WHO was claiming and trying to address through the UN Clean Cooking Alliance (CCA).

Table 18. Cookstove particulate matter emission 10 (microgram/ cu m of air)

Pot set up	Particulate Matter 10 emission	US EPA threshold
Sunken Pot	24	Less than 54 microgram/cu m of air
Fitted pot	32.67	
Open-fired	500	

Particulate Matter 2.5 Emission

For this test of the concrete made stove, sunken pot and fitted pot set up during the operation releases particulate matter lower than the US EPA threshold which means that the cookstove can significantly maintain a good level of indoor air quality (Table 19). On the other hand, open fire set up releases more than the standard threshold which may cause serious effect on the health of persons exposed it. That is why global initiatives like the UN Clean Cooking Alliance was exerting efforts to address this health concern in a global perspective.

Table 19. Cookstove particulate matter emission 2.5 (microgram/ cu m.)

Pot set up	Particulate Matter 2.5 emission	US EPA threshold
Sunken Pot	20.67	Less than 12 microgram/cu m
Fitted pot	25.67	
Open-fired	445.33	

Conclusion and Recommendation

This study further concludes that both stoves (GI sheet and concrete) are better in terms efficiency, fuel consumption and emissions whether it is operated under sunken pot and top fitted pot set up but not on the open fired pot set up.

To improve the stove, the following are recommended;

1. Try to consider other local materials that are less cost and abundant.
2. Improve the design of pot set ups by providing some additional rings.
3. Provide good material insulations for the GI or any metal made stove to reduce the heat dissipated and improve the stove HUE.
4. Improve the stove chimney by providing extendable of modular design to allow users to expel the smoke outside of the kitchen.

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Appendices

Appendix Table 1. US EPA Indoor Air Quality Threshold

US Environmental Protection Agency (US EPA) Air Quality Index (AQI)	
Air Parameter	Threshold of Good Indoor Air Quality
Particulate Matter 10 (PM10)	Less than 54 microgram/cu m
Particulate Matter 2.5 (PM2.5)	Less than 12 microgram/ cu m
Carbon Dioxide (CO2)	Less than 650 ppm
Carbon Monoxide (CO)	Less than 25 ppm

Appendix Figure. Photo Documentation



Bionote

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